Design Enquiry: Tacit Knowledge and Invention in Science

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Introduction

For some years there has been discussion and speculation on the subject of "design enquiry" and a number of people, for example Richard Buchanan[1] and Clive Dilnot[2], have looked for forms of enquiry appropriate to, or fruitful for, design as an academic and professional discipline. From a different perspective, Ranulph Glanville[3] has suggested that the relationship between design and science might be redefined to acknowledge similarities of method that are disguised by forms of narrative employed by scientists. However most contributions in these debates deal with generalisations so I would like to propose some specific ways in which designers can explore and develop the concepts and practices of design enquiry.

In particular I would like to discuss a kind of enquiry where designers can play a role in forming and pursuing questions which arise in the natural sciences and I will suggest that this role might be extended into some other fields. In doing so I will make reference to the subject of tacit knowledge, a concept which was formalised by Michael Polanyi in his consideration of the philosophy of science 50 years ago and which has attracted continuing interest (his 1958 book, *Personal Knowledge*, was

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[1] Richard Buchanan "The Study of Design: Doctoral Education and Research in a New Field of Enquiry," *Doctoral Education in Design Conference*, Ohio 1998

[2] Clive Dilnot, "The Science of Uncertainty: The Potential Contribution of Design to Knowledge," *Doctoral Education in Design Conference*, Ohio 1998

[3] Ranulph Glanville "Researching Design and Designing Research," *Design Issues*, 15, 2, 80-91

reprinted most recently in 1998 and 2002), but also some shallow interpretation since then.

I believe that Polanyi has a great deal to offer the design community, perhaps more in some respects than the widely cited work of Donald Schon who dealt with general questions of practice relevant to many disciplines while Polanyi addressed the relationship between enquiry and creativity in a very direct way.

In the natural sciences enquiry is concerned with uncovering or discovering that which exists. "Invention" is not considered to be a feature of scientific enquiry and is perhaps not compatible with the dispassionate relationship with knowledge that scientists have traditionally claimed. Design, by contrast, claims invention (and personal ownership of it) as a central principle so it is difficult at first to see where the two traditions can overlap. In this paper I will set out some ways in which they can cooperate and, in doing so, support the distinct goals of both.

Polanyi - Illumination and the Tacit Dimension

A central problem of science is how to recognise and define worthwhile subjects for investigation. For one thing, we may be faced with a myriad of opportunities and no means to decide which are going to be fruitful. On the other hand, our environment may limit our ability to recognise scientific problems and possibilities, especially the ones which could lead to significant changes in our understanding.

To illustrate this second problem, philosophers have speculated on the science and culture of imaginary worlds which have fundamentally different and more restricted conditions than ours. If you and your environment consist of gases with no solid objects to reflect on, then you may not be able to conceive of geometry as we know it. If you lived in a 1 or 2-dimensional world you would have a very different set of concepts from us and, no doubt, people living in a 5-dimensional world would see us as conceptually impoverished in much the same way.

Artists also engage with these issues, often in stimulating and accessible forms. For example science fiction writers explore imaginary worlds which shape their civilisations in ways that may inform us about our own experience. Brian Aldiss[4] described a world where each season lasted for many lifetimes, including a harsh

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4   Brian Aldiss "Helliconia Spring" *London, Jonathan Cape* 1982

winter which few people and institutions survived, effectively cutting people off from their history and most of the knowledge acquired during the previous summer. This fictional device provided a fresh perspective for the examination of individuals and societies confronted with difficult circumstances.

These abstracted questions have their parallels in everyday life and more mundane enquiries. Michael Polanyi[5] describes the 'logical gap' between existing knowledge and any significant discovery or innovation. No matter how thorough our factual knowledge of the situation that we inhabit, the pursuit of logical reasoning or iterative development of existing concepts would not, on its own, allow us to cross this gap. There must be also some kind of leap of 'illumination' by which the scientist imagines a new concept and proposes it as a worthwhile subject for investigation. As Polanyi says *"Illumination....is the plunge by which we gain a foothold in another shore of reality. On such plunges the scientist has to stake, bit by bit, his entire professional life."*[6]

If the gap between our existing situation and the new world which we wish to inhabit is made wider by our inability to conceive of what that world is like, that, I suggest, is where designers can help.

Polanyi was concerned with what he called the "tacit dimension" in our knowledge. In particular he wished to give proper value to the process of recognising, and making a commitment to, ideas or hypotheses, which may result from a rich understanding and knowledge but cannot be explained by explicit reasoning, in order to carry out the enquiry that will lead to them being more widely understood and accepted.

I have used the term "accepted" rather than "proved" (itself shorthand for Karl Popper's concept of a falsifiable hypothesis that has proved so far to be reliable) because Polanyi held that all scientific knowledge is a question of "passionate belief" rather than dispassionate proof, requiring us to take account of the methods, competence, judgement and integrity of scientists, and the knowledge and principles that we already hold, before we accept the knowledge which they offer us. This seems

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[5] Michael Polanyi "Personal Knowledge: Towards a Post-Critical Philosophy" *London, Routledge* 1958

[6] Polanyi, 123

much more reasonable today, when more people appreciate the limitations of science, than 50 years ago when Polanyi was developing his ideas.

So where does designing come in to all this? Through working with designers and scientists and observing other such collaborations, I have come to the conclusion, a "passionate belief" if you like, that the ability of designers to imagine new scenarios, and create a practical environment for us to experience them by producing experimental artefacts, is a valuable aid for scientists who want to identify ideas that merit investigation. Going further, it is possible that in some cases, the actual enquiry and its possible outcomes may be defined by a scenario designed to enable it.

Polanyi made a valuable contribution by asserting the importance of the "illumination" which guides scientific enquiry, suggesting that it could be more significant than the subsequent process of investigation. It is conventional, in reporting scientific findings, to emphasise the rigorous process of "proof" and pay very little attention to the genesis of the enquiry. I would like to suggest that the undervalued "creative" dimension of scientific enquiry needs to be emphasised and designers, through their practical contributions, can be instrumental in drawing attention to this.

Designing new worlds

I have referred so far to the natural sciences and that is the main area of opportunity that I wish to consider. However many of the ideas which inform these thoughts have arisen from interactions between design and the social sciences which have led to new ways of designing and a new role for the designer.

In a well known example, Pelle Ehn and Morten Kyng[7] described work on the design of computer systems where the designers had to overcome two important problems. Firstly they needed to draw on the knowledge and experience of people whose work would be supported by the new system, and secondly they did not have effective ways of prototyping design ideas which depended on new technologies not yet readily available or affordable (in the 1980s) or easily understood by their audience.

In response to this problem Ehn and Kyng adopted a technique, which they described as the "cardboard computer", using very simple paper and cardboard representations of the different parts of the system, for example a matchbox represented a mouse, a cardboard box was a laser printer and a piece of paper taped to the wall was a computer screen.

Although this might appear to be a crude approach driven by cost and expediency it had some significant advantages over more sophisticated prototyping. As well as being extremely fast to set up and modify it allowed the participants in the exercise to recognise that judgement was being suspended - they were engaged in an imaginative play activity in which they did not have to concern themselves with technical or organisational limitations, just explore the possibilities and problems of the ideas represented in the cardboard system. In addition anybody could modify the cardboard system. If you felt that the laser printer should be in a different position you just picked it up and moved it. If you thought the information on the computer screen should be shown differently you could change it yourself or draw a new screen on a fresh piece of paper.

This allowed the participants to play a very full and uninhibited role in the development process, a fact which was underscored by later experiences with real prototypes which could only be modified by computer experts, reducing the other participants to passive observers who would easily lose interest. The most important value of the cardboard computer process was the way it allowed participants to enter into an imaginary world (which they would not have been able to envision by other means), explore it and, most importantly, manipulate it to further their exploration.

This process unlocked the participants' tacit knowledge gained through years of practical experience. They acted out both the scenarios of their existing work and the new scenarios of the future workplace to build up a rich picture of how the new system might work. Arguably the "knowledge" which was thus mobilised was inaccessible by other methods and, most importantly, it only became "explicit" in the sense that it was embodied in the design and procedures of the new system.

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[7] Pelle Ehn & Morten Kyng "Cardboard Computers: Mocking-it-up or Hands-on the future" *in Greenbaum, J. & Kyng, M. (eds) Design at Work: Cooperative design of computer systems,* Hillsdale NJ, Lawrence Erlbaum, 1991 pp169-195. Similar techniques are now used in a number of fields and the terms "paper prototype" or "low-fidelity prototype are often used to describe them.

The idea that people's tacit knowledge can be somehow extracted and made explicit in the form of rules for all to employ is often expressed in the field of knowledge management but, in my view, it is fundamentally misguided. Each of us has a tacit understanding which allows us to respond to different situations differently but, in general, appropriately. It is possible to harness that understanding in activities that provide us with design ideas and principles, or with other insights helpful to our investigation but these will be new explicit knowledge. The original tacit knowledge held by an individual is unique to them, a product of their whole experience and not a direct source of generalisable knowledge.

Symbolic Languages and Rich Representations

If designers are to play a constructive role in multi-disciplinary enquiry we need to understand what will be different and helpful in their contribution. One feature of a design-based enquiry is that it can generate artefacts, another is that designers are skilled in organising and representing artefacts. This may not appear central to the idea of scientific enquiry, but it might become very significant if we consider the role that systems of representation have played in the development of thought.

The invention of symbolic languages allowed reasoning of a far greater scope than was possible before and it can be argued that it was only language that allowed us to transcend our relatives, such as chimpanzees, that are intelligent and inventive but unable to manipulate ideas with the kind of complexity that characterises human thought.

How we think, and the kinds of knowledge that we can develop, depend heavily on the symbolic languages available to us. Scientists and others may invent or adapt notations or vocabulary to facilitate their thinking and there is a constant tension between the requirements of specialist thought and those of comprehension by a wider audience.

Early written languages were pictographic and grew from literal pictures but today we use simplified abstract characters. Polanyi[8] suggested that, to be useful, a language should have a relatively small set of symbols which could be used flexibly to represent complex ideas, he called this the "poverty principle". Symbols or words

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[8] Polanyi, 77-82

which each represent single complex ideas create an unwieldy language which is much harder to learn. We need to work within a vocabulary of manageable size.

So it can be argued that the historical move from one-off literal pictorial representations to the generalised languages that we take for granted today is essential for the development of knowledge. However it may be profitable to consider how different forms of representation, including complex, very specific artefacts, can support our efforts to employ tacit knowledge in our enquiries, whether we are seeking to engage our own tacit processes or those of our audience. This tension between simplified generic symbols and complex specific representations reflects the relationship between atomistic methods which have been so successful in advancing scientific knowledge and the holistic outlook needed for successful design.

To illustrate this I would like to give an example from research that included the experimental use of creative design practice and resulted in the accumulation of artefacts that had been produced or employed in the research. As well as being evidence of process, such a collection can also act as a visual notebook of the research, readable by those who have been involved in it.

Efforts were made to exploit this resource, initially by simply laying out all the research material in one space to facilitate a review of the project.[9] It was apparent that the collection of drawings and 3D objects provided a record of the research in which all aspects of the work could be seen and encompassed, in a holistic fashion by the researchers.

The connections between the many different aspects of the research, and the great variety of narratives embedded in it, could all be traced without losing the overall picture. Subsequently it was possible to construct a large number of simpler composite images, each collecting together material relevant to an aspect of the work and providing a basis from which that part of the research narrative[10] could be constructed.

This activity was similar to Ehn and Kyng's 'Cardboard Computer' in that it provided an environment in which the researchers could reflect on their work in a comprehensive way and employ tacit as well as explicit knowledge to identify and

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[9] This work was described in detail by Chris Rust & Adrian Wilson in "A Visual Thesis? Techniques for Reporting Practice-Led Research" *Proceedings of the 4th European Academy of Design Conference,* Aveiro, Portugal, April 2000, 68-72

trace ideas, connections and experiences from its history. The artefact record was quite different from written notebooks which do not provide a complete picture "at a glance" and require their owner to maintain a complex mental picture (not accessible to collaborators) of their work if they are to navigate and exploit their records.

Polanyi used the term 'indwelling' to describe the process whereby a person engages in a task that develops and employs tacit knowledge. For example an experienced car driver may attend explicitly to the route that they want to follow but pay very little attention to the car that they are driving or its controls. They dwell in the familiar task of driving and rely on their tacit knowledge to take care of it for much of the time. Take them out of the car and they may be unable to describe with any precision how it was driven in a given situation.

The provision of a rich set of images or artefacts, as described in the example above, provides an environment in which an individual can dwell in their work and employ their tacit knowledge. The reason that I have pursued this thread is to suggest that, while Polanyi is probably correct to say that simple languages with abstract general-purpose symbols are necessary for the development of knowledge, there is still a place for rich, complex, literal representation and the authors of early cave paintings may have understood something about the role of indwelling that has been lost in our almost universal adoption of text as our primary recording medium.

There is a further, celebrated example of an investigation which was advanced by the use of designerly methods and rich representations. The story of Watson and Crick's solution to the puzzle of the DNA molecule is well known, as are the images of the three-dimensional model that they used to think through the problem of how this very complex molecule might be constructed. The basic principle that the molecule might have a helical form was identified by Rosalind Franklin using photographic techniques to examine the molecule, but the way that form was constructed and interlinked, and the crucial idea that the molecule was a pair of identical helixes that could divide to form two new molecules was worked out by Watson and Crick whose method was based on the construction of analogous models of sheet metal and cardboard.

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[10] Graham Whiteley "An Articulated Skeletal Analogy of the Human Upper-Limb" *PhD Thesis, Sheffield Hallam University, UK,* 2000

Watson describes how they adopted the methods demonstrated by their rival in the DNA race, Linus Pauling:

The key to Linus' success was his reliance on the simple laws of chemistry……..the essential trick was to ask which atoms like to sit next to each other. In place of pencil and paper, the main working tools were a set of molecular models superficially resembling the toys of pre-school children. We could thus see no reason why we should not solve DNA in the same way. All we had to do was construct a set of molecular models and begin to play[11]

Given the 3-dimensional complexity of their problem, it was only by constructing and, arguably, dwelling in their model that Watson and Crick could make the mental connections needed to complete the puzzle. Watson's own account of the enterprise makes it clear that there was a tension between the philosophy of Rosalind Franklin, who believed that thorough analytical work would yield the secret of DNA and focused all her efforts on photographic analysis methods, and the approach of Watson & Crick who believed, with Linus Pauling, that DNA was a geometric problem best understood by 3-D modelling. In fact both approaches were needed, as demonstrated by the Nobel Prize Committee making their award jointly to Watson, Crick and Franklin's colleague, Maurice Wilkins[12]. It was Watson's opinion that Wilkins' team at London University might have been the first to solve the DNA puzzle if Franklin had not been so firmly against using physical models which, in her eyes, lacked proper scientific rigour[13].

Investigative designing

To give some examples of how these ideas can work, I would like to describe some recent cases of designers working in collaboration with scientists. Peter

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[11] Watson, J.D. "The Double Helix" *Signet, New York, 1969, 38* (first published by Athenium, 1968)

[12] Rosalind Franklin had died by then and Nobel awards are not made posthumously

[13] In "The Double Helix" Watson described Franklin's hostility to the technique of modelmaking (p51). He was clearly worried when Maurice Wilkins, borrowed the Cambridge moulds for making molecular models and relieved when he discovered that the moulds had not been used by Wilkins' team. It took several years for Wilkins to confirm the Watson and Crick description using analytical methods, adding to the evidence that the modelling approach was the key to the discovery even though other methods were needed to support and confirm it.

Walters[14] and his colleagues describe work concerned with understanding ways to discriminate between the different tube connections used to deliver medication to hospital patients. This was a problem which was of grave concern because mistakes in connecting tubes can kill or seriously injure people.

This can be thought of as a problem of cognition and most people involved assumed that psychologists would tackle it. When a design team was proposed as part of the research effort it was difficult for many of the participants to understand why designers were needed at this early, theory-building stage. The designers developed a series of prototype connectors which explored the problem of tactile and visual differentiation and provided the research team with something to test on human subjects. The design process allowed some early "quick and dirty" evaluation of possible strategies as well as more rigorous testing of the more promising options. As a result, not only did the research provide strong direction for an international programme seeking to develop standards in this area, but it has also led to recognition of the need for (and strategies for developing) a more wide ranging understanding of how tactile discrimination can operate in different circumstances.

In a second example, the Information Design group at University of Idaho[15] are working on methods for representing scientific data. This started as a professional practice teaching program providing new career paths for graphic design graduates but, in exploring the issues with scientists, it appears that there may be benefits which go beyond the immediate communication problem (in itself a difficult concept for scientists who imagine that the designers are offering help to glamourise their powerpoint slides).

For example, one discussion of possible approaches to representing data in a medical research project led directly to the researcher identifying significant patterns in the data which led, in turn, to a proposal for clinical applications of the research. It is

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[14] My description here is based on frequent conversations with the researchers, who are based in Sheffield, as well as the published outputs. The project is described in Peter Walters, Paul Chamberlain and Mike Press "In Touch - An investigation of the benefits of tactile cues in safety-critical product applications" *Proceedings of 5th European Academy of Design Conference, University of Barcelona,* April 2003

[15] The group includes Frank Cronk, Jill Dacey and Colleen Taugher. The work was described by Professor Cronk in a talk at the 2002 Information design conference at Reading University, UK. Subsequently the specific issues referred to here, and the text of this paper were discussed in an email "conversation" with Prof Cronk.

particularly interesting that the designer's contribution in that case was limited to discussing how to communicate data, and this new perspective was sufficient to change how the scientist perceived the data. Clearly the scientist had the data and the knowledge (tacit and explicit) to carry the research forward, but the designer's ability to work with and re-frame representations provided a valuable catalyst.

Gary Gowans and Jim Campbell of Dundee University are multimedia designers who were invited to take part in a project concerned with reminiscence therapy for Altzheimer's disease sufferers[16], collaborating with academic colleagues in departments of Psychology and Applied Computing.

They were able to introduce both a number of imaginative ideas for ways to apply the underlying theories, and a design approach based on a good understanding of usability. While the success of the project depends on the specialist knowledge and research methods of all the partners, it is difficult to imagine the project making such significant progress without the involvement of designers able to envisage and prototype realistic multimedia resources that reflect both the scientific understanding behind the project and the wider agendas of the different "stakeholders" in the project.

In their published discussion of the project the designers draw attention to the importance of recognising the expertise of their collaborators and also of overcoming designers' natural tendency to assert their individual roles rather than value teamwork. Arguably one advantage of this sort of collaboration is that it allows individual designers to make a significant creative contribution while also recognising that teamwork is important in the bigger picture of the research.

For my final example, as a process of investigating possible analogies for the joints of the human arm, Graham Whiteley[17] designed and produced a model arm including mechanical joints that provided a very close match for the movement of the original joints of the body, despite being constructed quite differently. In evaluating the results we invited a number of experts, such as surgeons and osteopaths, to

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[16] Gowans, G. Campbell, J. Astell, A. Ellis, M. Alm, N. Dye, R. "Designing CIRCA: A Multimedia Conversation Aid for Reminiscence Intervention in Dementia Care Environments" *Proceedings of European Academy of Design Conference, University of Barcelona, 28-30 April 2003*

[17] This project took place in Sheffield between1997 and 2001. The work was proposed and carried out by Graham Whiteley in the Art and Design Research Centre of Sheffield Hallam University and supervised by Adrian Wilson, of University of Sheffield Medical Physics Dept, and myself. Fuller details may be found in Whiteley and in Rust & Wilson.

manipulate the resulting skeletal arm and found that they were able to recognise subtle features of the model very quickly, identifying how it matched and differed from the original. The model arm allowed them to mobilise their tacit knowledge of anatomy, gained from many years of regularly manipulating people's limbs.

This was significant in two ways. Firstly it complemented the relatively unreliable quantitative data available (measuring skeletal movement is a difficult art so most published data is suspect and provides limited information) and secondly it stimulated a number of ideas and observations by the participants. An elbow surgeon commented that the design indicated ways to improve the design of replacement elbow joints, an osteopath pointed out that there were subtle damping effects due to soft tissue surrounding normal joints and absent in the Sheffield arm, and a clinical engineer has proposed a development of the research to provide an additional dimension to surgical simulations.

These examples show how a designer's ability to embody ideas and knowledge in artefacts can give us access to tacit knowledge, and can stimulate people to employ their tacit knowledge to form new ideas. Sometimes, as in the analogous arm, the designer is engaged in developing new knowledge on their own account, in other cases their role may be to table propositions or hypotheses in accessible forms that can stimulate people to evaluate and develop the ideas further.

The main aim of this paper has been to develop ideas about investigative designing and to indicate ways that designing can be complementary to other research practices. The forms of research described here indicate one of the most interesting features of designing - it takes place in almost every context and can contribute to understanding and our experience in almost every context. While it may be legitimate for "design researchers" to consider the special arenas and activities peculiar to designing, for designers themselves there is a much wider world of knowledge and experience that they can engage with and influence and this is as true of research as it is of the more usual forms of creative practice.

There are two barriers to this. The first is in the designer's self-image. If designers imagine that research and creation of knowledge is a matter for others then they will always find themselves in a subsidiary role (or no role at all) in research. To overcome this takes not only self-confidence but a proper appreciation of, and respect for, the knowledge and methods of scientists.

The second problem is the perceptions of possible collaborators, who will not recognise the contribution that designers might make and here I can only recommend that designers seek collaborators who have open minds, but it will be necessary also to be subversive, to find opportunities to demonstrate what can be achieved and expect to invest some effort in doing that before partners start to understand the possibilities. Luckily designers have ways to demonstrate their contribution that do not require rational argument or a formal definition of their role in a project. If an energetic and able designer can find any role at all in a research environment they can quickly develop that role by creating and deploying artefacts that affect the work in hand and demonstrate their ability to make a difference.